BBC RD 1977/13

BBC

RESEARCH DEPARTMENT

1974 THE QUEEN'S AWARD TO INDUSTRY

REPORT

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THE BRITISH BROADCASTING CORPORATION

March 1977

BBC RD 1977/13
UDC 621.397.331.244.1

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Summary

This report summarises the physical characteristics, convergence systems and the interaction between the picture information and the mask structure for two types of shadow-mask tubes with in-line guns. One tube has a 51 cm screen and 90° deflection angle; the positions of the scan yoke and the convergence components (purely static) have been determined by the manufacturer and the components cemented into position. The other tube has a 66 cm screen and a 110° deflection angle. It requires dynamic convergence controls but these are considerably simpler than those of the traditional dot-phosphor shadow mask tube.

Issued under the authority of

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BRITISH BROADCASTING CORPORATION

March 1977

(PH-173)

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1. Introduction

In a conventional shadow-mask display tube the delta layout of the guns, with Red and Green at the bottom and Blue at the top, causes the three beams to pass through different parts of the electrostatic accelerating fields and the magnetic deflecting fields. The resulting convergence errors require both static and dynamic convergence-correcting fields to be applied to the individual beams, the dynamic fields involving both sawtooth and parabolic components at line and field frequencies. The adjustment of these convergence correcting fields is a skilled operation and the settings may depend on the e.h.t. voltage and the scan geometry. The apertures in the shadow mask are circular holes; the beams passing through a hole strike a triad of phosphor dots in a triangular pattern. Fig. 1 shows the layout near the centre of the display.

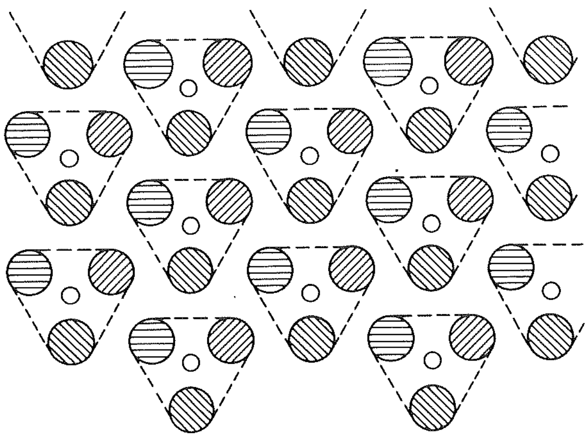
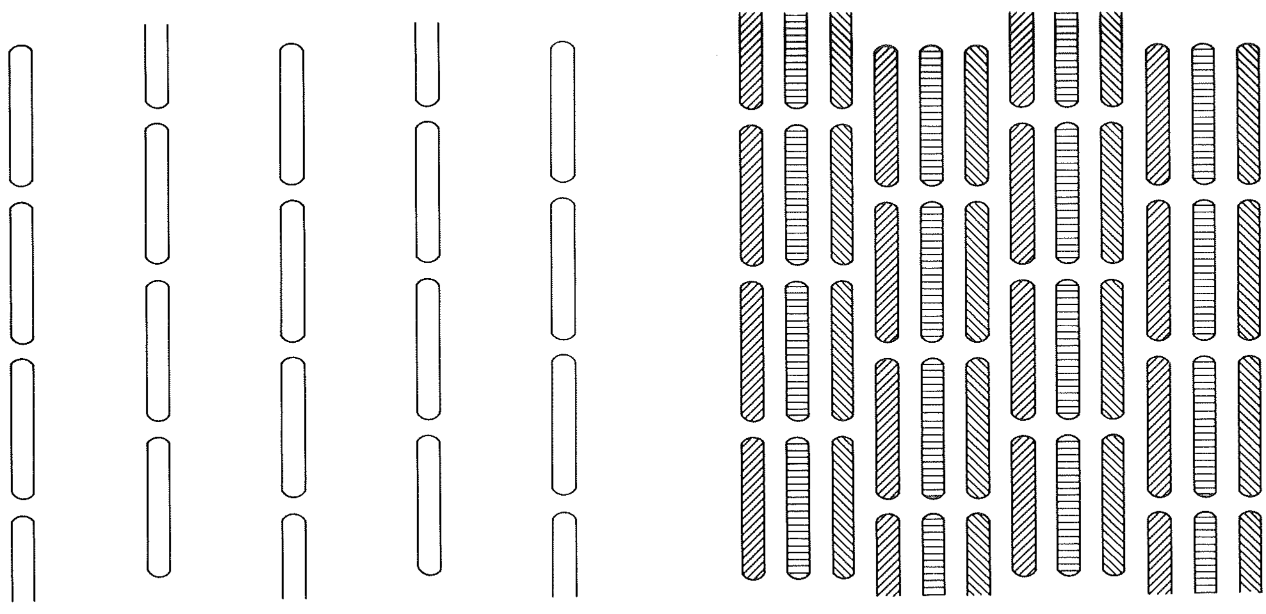


Fig. 1 - Phosphor triads near the centre of the screen of a standard shadow-mask tube

Red, Green, Blue — Phosphor dots   O Hole in shadow mask

An alternative type of shadow-mask tube has been developed in which the three guns lie in a horizontal plane, usually referred to as an 'in-line gun' tube.[1,2] The apertures in the mask are vertical slots (Fig. 2(*a*)) and the phosphor triads are narrow stripes (Fig. 2(*b*)). The electrode assembly and the scan-coil windings are designed so that the beams converge at the screen; if the three beams are regarded as the central and outside components of a wide ribbon of beam, the fields bring it to a focus at the screen. The basic symmetry of the tube about the plane through the gun makes this practicable to a degree that cannot be realised in a delta-gun tube. Because definite action is required to converge the beams in the horizontal direction, whereas in the vertical direction they are intrinsically convergent (apart from errors introduced by non-uniformity of the fields), this focusing action is astigmatic.

If the tube elements and the scanning coils are well



(*a*)   (*b*)

Fig. 2 - The shadow-mask tube with in-line guns

(*a*) Slots in the shadow-mask   (*b*) Phosphor strips

Red   Green   Blue

designed and accurately made, the purity and convergence adjustments may consist only of the correct positioning of the scanning coil assembly and the four-pole and six-pole permanent ring-magnets on the neck of the tube.

This Report assesses some characteristics of two in-line-gun tubes, but because they differ in basic concept no comparisons may be drawn between their standards of performance.

The smaller tube was made by Thorn Industries but is no longer in production in the U.K. Its nominal screen size was 51 cm, with a 90° deflection system. The positions of the scanning coils and the static purity/convergence magnets had been adjusted by the manufacturer and they had been cemented in position. No dynamic convergence elements were required.

The larger tube was made by Mullard Ltd. Its nominal screen size was 66 cm, with a 110° deflection system. The manufacturers had chosen, for production and commercial reasons, to specify the tubes and their yokes so that any tube and yoke combination would result in a satisfactory unit when correctly adjusted and provided with a small degree of dynamic convergence which would, in effect, be compensation for the manufacturing tolerances.

2. Physical characteristics of the tubes

The characteristics of the tubes are given in Table 1. Figures enclosed by single brackets are nominal values, those enclosed by double brackets are estimated from the available data and the others are measured values. Each tube was incorporated in a domestic u.h.f. television receiver, the input signal being a locally-generated vision carrier, modulated by appropriate composite video waveforms. For some tests the normal video drives to the tube cathodes were replaced by the output from a high-level amplifier.

Because the convergence system of an in-line-gun is much simpler than that of a traditional shadow-mask tube, the tube-neck components are smaller and lighter, and the

TABLE 1

Tube	Thorn A51–161X	Mullard A66–500X
Nominal size	(51 cm)	(66 cm)
Deflection angle	(90°)	(110°)
Screen diagonal	49 cm	63·4 cm
width	40·4 cm	52·8 cm
height	30·3 cm	39·8 cm
Spacing between guns	(5·08 mm)	
Scanning coils	Toroidal. Cemented in position by manufacturer	Modified saddle. Position adjustable
Neck diameter	(29 mm)	(36·5 mm)
Overall length of tube	(417 mm)	(412 mm)
Purity	Accurate positioning of scan coils, cemented in position	Adjustable scan coil position and pair of two-pole magnets
Convergence	Static only, by 4- and 6-pole permanent magnets, cemented in position.	Static: 4- and 6-pole permanent magnets. Dynamic: 7 controls
Horizontal spacing of phosphor triads	(0·826 mm)	(0·795 mm)
Mask bridging (vertical interval)	((0·82 mm))	(0·81 mm)
Centre colour of trio	Red*	Green
Phosphor chromaticities		
Red at 2 ft-L (7nt)	$x = 0{\cdot}616, y = 0{\cdot}346$ $u = 0{\cdot}416, v = 0{\cdot}351$	$x = 0{\cdot}623, y = 0{\cdot}338$ $u = 0{\cdot}429, v = 0{\cdot}349$
Green at 16 ft-L (55 nt)	$x = 0{\cdot}324, y = 0{\cdot}575$ $u = 0{\cdot}140, v = 0{\cdot}373$	$x = 0{\cdot}311, y = 0{\cdot}599$ $u = 0{\cdot}130, v = 0{\cdot}376$
Blue at 1·5 ft-L (5nt)	$x = 0{\cdot}164, y = 0{\cdot}065$ $u = 0{\cdot}190, v = 0{\cdot}114$	$x = 0{\cdot}154, y = 0{\cdot}063$ $u = 0{\cdot}178, v = 0{\cdot}110$
Limiting horizontal resolution determined by the mask (Nominal cut-off frequency = ½ sampling frequency)		
No overscan	((4·7 MHz))	((6·4 MHz))
5% overscan	((5·0 MHz))	((6·7 MHz))

Single brackets ( ) denote nominal value
Double brackets (( )) denote a value calculated from nominal values. Other values are as measured.

* Comparable RCA tubes have the Green phosphor in the centre.

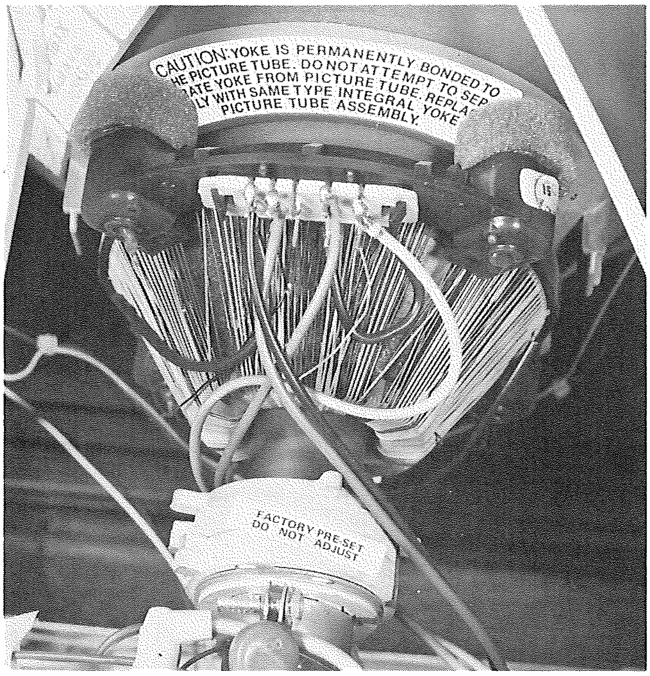


Fig. 3 - Neck assembly components, Thorn tube

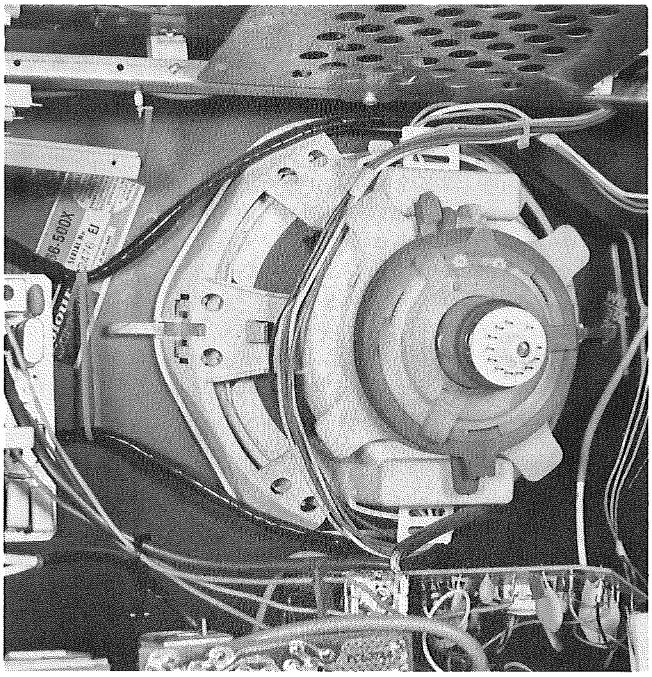


Fig. 4 - Neck assembly components, Mullard tube

tube neck can be reduced in length with a consequent reduction in the size of the receiver cabinet. Figs. 3 and 4 are photographs of the neck assemblies of the two tubes.

3. The chromaticities of the phosphors

The chromaticities of the phosphors were measured, using the spectrophotometer method recommended by the I.E.C.,[3] and are given in Table 1. The standard primaries for PAL system have co-ordinates.

Red	$u = 0{\cdot}451$	$v = 0{\cdot}349$
Green	$u = 0{\cdot}121$	$v = 0{\cdot}374$
Blue	$u = 0{\cdot}175$	$v = 0{\cdot}105$

The phosphors of the Mullard tube lie within the acceptable limits for studio monitors used in the BBC, but the phosphors of the Thorn tube are outside these limits.

4. Convergence

The purity and convergence controls of the Thorn tube were adjusted by the manufacturer and sealed in position. Errors of convergence were extremely small and no dynamic convergence controls were required.

The Mullard tube has a larger deflection angle (110°). The two static and seven dynamic convergence controls were adjustable but the convergence errors could not be reduced to the level of those in the Thorn tube. Nevertheless it is clear that, with better control circuits, this could be improved.

Only one tube of each type was tested and it is not possible to say whether these results are typical.

5. The effects of the shadow-mask structure on resolution and moiré patterning

At low currents the width of the beams of in-line gun tubes, at the plane of the shadow-mask, is approximately equal to the horizontal spacing between the apertures. Considering the behaviour of one phosphor colour at a time, the video information is sampled at the spatial frequency of the aperture slots.

The classical theory of sampling in a linear system shows that if an input waveform is sampled at a frequency f_s and if the waveform after sampling is passed through a perfect low-pass filter whose cut-off frequency f_c is less than $\frac{1}{2}f_s$ (however small the difference $(\frac{1}{2}f_s - f_c)$ may be), any component of the input waveform at a frequency f_{in} which is below f_c results in a component of the same frequency at the filter output. If f_{in} lies between f_c and $(f_s - f_c)$ the filter rejects the corresponding component of the output from the sampler, but if f_{in} lies between $(f_s - f_c)$ and $(f_s + f_c)$ the filter output contains a component at $(f_s \sim f_{in})$ which is different from f_{in} and is commonly known as an 'alias' component. Similar alias components occur when f_{in} lies within the range $\pm f_c$ of any harmonic component of the sampling waveform, and the frequencies of the alias components are low when the input frequencies are close to the sampling frequency or its harmonics.

The sampling in these display tubes differs from this in two main ways.

(a) Although imperfections in the tube and the eye produce a low-pass filtering effect the rate of cut-off is

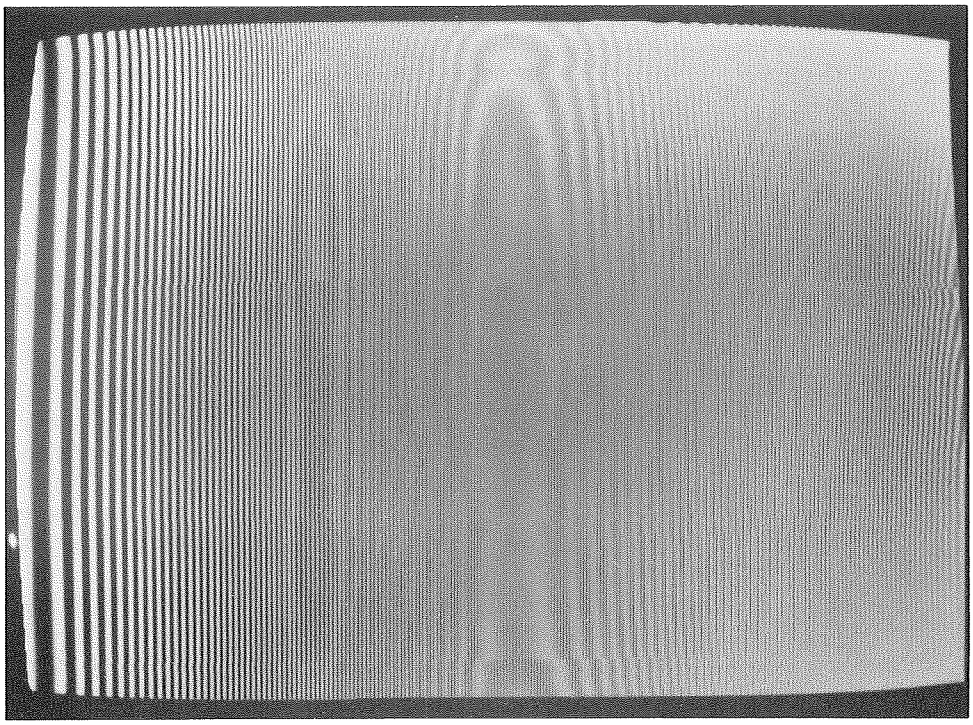


Fig. 5 - Display using the green phosphor only Frequency sweep 0·5 to 10·0 MHz applied to tube cathode. Overscan approximately 4%.

slow and there is an appreciable response at spatial frequencies above half that of the aperture slots.

(b) The relationship between the tube-luminance and the signal-drive modulating the beam is non-linear (approximately a power law with exponent $\gamma = 2{\cdot}8$) so a sinusoidal variation with time of the applied signal results in a non-sinusoidal variation with distance of the display luminance; thus harmonics are generated which are sampled by the structures of the shadow mask and the phosphors.

As a result, aliasing components appear on the display, accompanied by low-frequency patterns when the video display contains a component at a frequency which has a harmonic of the sampling frequency. This is discussed in detail in the Appendix. The patterning may be more apparent in a photograph than when the screen is viewed directly.

Fig. 5 is a photograph of a display on one of the tubes. The signal, applied directly to the cathode of the Green gun, consisted of a d.c. component and a sinusoidal signal that was swept at line-frequency from approximately 0·5 to 10 MHz. The Red and Blue guns were cut off, and a modulated signal applied to the normal r.f. input of the receiver to control the line- and field-timebase synchronisation. The receiver was about 5% overscanned.

Moiré patterns were produced where the video frequency was $^1/_3$, $^1/_2$ and $^2/_3$ of sampling frequency (from left to right), and the extreme right-hand side of the display shows the effect of the video frequency beginning to approach the sampling frequency. The variations of the patterns in the vertical directions are caused by:

Line-to-line variations of the frequency and phase of the swept sinusoidal waveform.

Line-to-line variations of the line scan, and

Non-uniformity of the spacing of the aperture slots.

The conditions of this test were not strictly equivalent to those in a normal television display, partly because the receiver or monitor has a restricted bandwidth which is not likely to exceed 5·5 MHz and may well be less, and partly because the input signals would have been gamma corrected. Low frequency signals that are sinusoidal before gamma correction produce approximately sinusoidal variations of beam current and do not result in significant moiré patterning. For signal components at frequencies in the upper half of the passband the voltage drive to the display tube is sinusoidal (apart from any distortion introduced by the detector or video amplifier in the receiver) and moiré patterns can be produced. Signal components at frequencies outside the passband are rejected.

If all three guns were driven simultaneously, on their cathodes, by swept sinusoidal signals producing a nominally monochrome, though not a primary-colour, display the three beam currents would vary in amplitude simultaneously. Under conditions of perfect convergence the sampling times of the three beams would be the same and the moiré pattern would result from the smoothing by the eye of the excitation of the phosphor triads rather than the single-colour phosphor strips shown in Fig. 5. However, quite small convergence errors produce significant differences between the sampling times of the three beams for high frequency signal components, resulting in phase differences in the moiré patterns of the three primary colours, as though they had different vertical variations in a display equivalent to Fig. 5. Thus a moiré pattern consisting predominantly of luminance variations would be converted into a less noticeable combination of a reduced luminance pattern and a chrominance pattern by small residual convergence errors whose effects on colour registration would be almost imperceptible.

The nominal centre-frequencies of the dominant moiré patterns for the two tubes are given in Table 2. The middle column of figures, i.e. the condition in which the frequency of the video component is half of the sampling frequency, is also the nominal cut-off frequency of the tube.

TABLE 2

Nominal Centre Frequencies, MHz, of Moiré Patterns

	Ratio video frequency/ sampling frequency		
	1/3	1/2	2/3
Thorn tube, nominal scan	3·1	4·7	6·3
5% overscan	3·3	4·9	6·6
Mullard tube, nominal scan	4·3	6·4	8·5
5% overscan	4·4	6·7	8·7

When an in-line-gun tube is used in a domestic receiver with a typical restricted luminance pass-band the cut-off frequency of the tube and the moiré patterning caused by picture components at frequencies near to cut-off may not be noticeable — on the receivers tested the patterning was just perceptible on the attenuated high-frequency bars of Test Card F. However, if such a tube were used in a high-quality studio monitor the effects of the moiré patterns could be appreciable and the lower cut-off frequency of the smaller tube could result in noticeable aliasing.

Other workers have reported that the alpha-numeric displays used in the CEEFAX system are satisfactorily reproduced by these in-line-gun tubes, even with no overscan.

6. A comparison between shadow-mask tubes with delta and in-line guns

The purity and convergence adjustments of tubes with in-line guns are inherently simpler than those of tubes with delta guns. For medium (56 cm) and small sized tubes it is technically possible for the adjustments to be pre-set by the manufacturer and sealed, but for production and commercial reasons this may not always be desirable.

The phosphors of the in-line gun tubes are arranged in vertical stripes, whereas the phosphor dots of the traditional tubes are in a higher-frequency interlaced pattern. The in-line gun tube is therefore the more likely to produce moiré patterns between the phosphor structure and the video information. On the other hand the in-line-gun tube is less susceptible to beats between the phosphor structure and the line-scan structure, which calls for care in the design of the triad spacing in dot-phosphor tubes. The in-line-gun tubes examined are fully satisfactory for receiver displays, including those provided by CEEFAX, but liable to produce some patterning in high-definition systems. It should be borne in mind, however, that the phosphor stripe spacing of current tubes remains sensibly constant regardless of the tube size. For applications requiring a tube with a diagonal of less than 51 cm, for example small monitors in Outside Broadcast vehicles, the vertical lines of a CEEFAX display are reproduced less satisfactorily and aliasing problems occur at lower frequencies.

7. Acknowledgements

This Report is published with the agreement of Mullard Ltd. and RCA but the statements made are the views of the author.

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9. Appendix

Sampling Theory Applied to an In-Line-Gun Tube

The action of the shadow-mask apertures and the phosphor stripes of one of the primary colours can be treated, to a first approximation, as spatial sampling by a rectangular pulse waveform in which the ratio of pulse-spacing (X) to pulse-width is k. To allow for the practical rounding of the sampling pulse the value of k would be taken as approximately 5.

The sampling waveform can be analysed into a 'mean' component A_0 and components A_1 A_2 A_3 A_4 etc. at the fundamental spatial frequency of the samples, $\omega_s = (2\pi/X)$ radians/mm, and its harmonics.

For a rectangular waveform

$$A_1 = A_0 \frac{\sin(\pi/k)}{(\pi/k)}$$

$$A_2 = A_0 \frac{\sin(2\pi/k)}{(2\pi/k)}$$

$$A_n = A_0 \frac{\sin(n\pi/k)}{(n\pi/k)} \quad \text{where } n \text{ is any integer}$$

Putting $k = 5$,

$$A_1 = 0{\cdot}94A_0$$

$$A_2 = 0{\cdot}76A_0$$

$$A_3 = 0{\cdot}50A_0$$

etc.

If the drive signal to the tube gun consists of a d.c. component and an a.c. component producing a repetitive pattern at a spatial frequency ω radians/mm the tube luminance may be written as the sum of a series of terms:

$$B = B_0 + B_1 \sin(\omega x + \phi_1) + B_2 \sin(2\omega x + \phi_2) + $$
$$+ B_m \sin(m\omega x + \phi_m) + \text{etc.}$$

where m is any integer.

Even if the voltage drive to the gun were a sinusoidal function of the deflection, the gamma law of the tube would result in harmonic components of B. The sampling action is represented mathematically by multiplying the sampling waveform by the luminance waveform that would have been produced without sampling.

A typical term of this product is

$$A_n \cos(n\omega_s x) \times B_m \sin(m\omega x + \phi_m)$$
$$= \tfrac{1}{2} A_n B_m \left[\sin\left\{ (n\omega_s + m\omega)x + \phi_m \right\} - \right.$$
$$\left. - \sin\left\{ (n\omega_s - m\omega)x - \phi_m \right\} \right]$$

If $(n\omega_s - m\omega)$ is small the second half of this is a low-frequency alias component that would result in a moiré pattern. Typical conditions occur when the spatial frequency of the luminance component is close to $1/3$, $1/2$, $2/3$ etc. of the sampling frequency. These are shown as patterns in Fig. 5, where the extreme right hand side shows the aliasing components produced when the luminance component frequency approaches the sampling frequency. When the ratio n/m is equal to $1/3$, $1/2$, $2/3$ etc., the luminance is determined by the phase angle ϕ_m. Non-uniformities in the scan, the slot spacing or the sweep waveform produce variations of ϕ_m from line to line, causing the vertical variations in the patterns shown in Fig. 5.

The measured screen width of the Thorn tube is 40·4 cm and the nominal spacing of the phosphor triads is 0·826 mm. Taking the active line time in PAL (I) as 52 μs and assuming that the active line just fills the screen, the video frequency corresponding to the sampling rate (for a linear scan) is

$$\left(\frac{404}{0{\cdot}826} \times \frac{1}{52} \right) = 9{\cdot}4 \text{ MHz.}$$

The nominal cut-off frequency is then 4·7 MHz.

If the receiver were 5% overscanned, the nominal cut-off frequency would be (9·4 x 1·05)/2 = 4·94 MHz.

Without overscan, the centres of the other moiré patterns in a display similar to Fig. 5 would be at $1/3$ of 9·4 = 3·14 MHz and $2/3$ of 9·4 = 6·27 MHz.

The measured screen width of the Mullard tube is 52·8 cm and the nominal spacing of the phosphor triads is 0·795 mm. Without overscan, the nominal equivalent sampling frequency is

$$\left(\frac{528}{0{\cdot}795} \times \frac{1}{52} \right) \text{ MHz} = 12{\cdot}77 \text{ MHz.}$$

The nominal cut-off frequency without overscan is 6·39 MHz and the centres of the moiré patterns at 4·26 MHz and 8·51 MHz.

Other workers, using nominal screen widths and different specifications of the shadow mask have calculated marginally different sampling frequencies.

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